Quantifying the Negative Impact of Mobility and Location Service Inaccuracy on Geo-Routing in Urban Vehicular Environments

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Abstract. Vehicular routing has been an extremely active research field in recent years with geo-routing protocols typically favoured over conventional topology based routing protocols due to their advantages in terms of scalability and lower overhead. Before a geo-routing protocol can transmit a packet, it must be aware of the position of the target node and is reliant upon a location service to supply this information. Therefore the correct and efficient operation of the routing protocol is entirely dependant on the accuracy of this information. In this paper, a simulation based analysis is conducted to determine the tolerance of a geo-routing protocol to position inaccuracy as reported by a location service. As the inherent mobility of a vehicular network may also have a negative impact on protocol performance, we also evaluate characteristics such as vehicular density, transmission range and query range.

Keywords: Vehicular Ad-hoc Networks (VANETs), Location Service, Geo-Routing Protocol.

1 Introduction

Over the past number of years, all major automobile manufacturers, often supported by government research initiatives, have invested in vehicular research, with vehicular communication networks poised to have a large societal impact. While the primary impetus in this space has been towards traffic information and safety systems, many platforms have been proposed promising a plethora of next generation vehicular applications such as distributed gaming, the evolution of vehicular communities for file sharing and social networking, infotainment and P2P content distribution applications amongst others. Given the infancy of this field of study, it still remains unclear which exact applications will prevail, but it can be envisaged that future vehicular applications will become highly customizable and will be based on a combination of broadcast, multicast and unicast communications.

A commonality of Vehicle-to-Vehicle (V2V) unicast applications is the requirement to discover the location of a destination vehicle towards which traffic can be routed. This is a necessary requirement for geo-routing protocols, which are the typical method employed to enable multi-hop data communication in vehicular networks. In recent years many VANET-specific geo-routing derivatives have been proposed to overcome

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the drawbacks of traditional geo-based routing protocols. All of these need to discover the destination location prior to forwarding. Intermediate nodes subsequently extract the destination position from the packet to make a decision regarding the next hop according to the geo-routing algorithm employed. To discover the destination location, the source vehicle firstly references a location service which stores a mapping for each vehicle ID to its current location – it is the responsibility of each individual vehicle within the network to update the location service index at regular intervals to ensure its accuracy. Since the correct and efficient operation of any geo-routing protocol is entirely reliant on the accuracy of the destination information returned by the location service, this is a vital field of study if vehicular unicast communications are to succeed.

Interestingly, while geo-routing has been a very topical area of research in vehicular networks, the location service algorithms utilized are typically treated as an orthogonal issue and are largely studied as mutually exclusive research areas. While many of the recently proposed VANET specific geo routing protocols exhibit excellent performance, they either assume the existence of a perfect location service or neglect to specify how the destination's position would be determined. Others simply employ location algorithms developed for generic MANETs that have been shown in literature to exhibit poor robustness and location accuracy over vehicular environments. Given the significant impact that a location service has on geo-routing protocol performance and the difficulty in maintaining either an available or accurate service in highly dynamic networks, this is not a valid assumption.

Specifically a location service algorithm must specify methods for efficient location update and maintenance, techniques for requesting and retrieving location information and ensuring the availability of the location service. The overall design objective is to limit the location inaccuracy within the algorithm while maintaining availability of the location service to each vehicle. Thus the challenge of a scalable distributed location service algorithm is a difficult one, particularly given a high level of dynamism. The challenges can be categorised as follows:

- Availability of the location service (as unavailability will render the geo-routing protocol defunct with the exception of localized communications) and the overhead associated with maintaining availability.
- Accuracy of location Information and the impact on the packet delivery rate of the respective geo-routing protocol when inaccurate location information is provided. Inability of a location server to receive location updates will also lead to stale location information when the service is queried.
- Scalability of the location service update mechanism and efficient resolution of location queries between vehicles at geographically disparate locations with minimum overhead.

Given the inherent importance of a location service, the focus of this paper is to evaluate the impact of location inaccuracy on geo-routing protocol performance and the effect of topological conditions on the success rate. Location inaccuracy can occur due to stale location entries as a result of delayed or lost position update packets. Factors leading to reported position inaccuracy include packet collisions, lack of route availability as a result of a partitioned/sparse ad-hoc network or temporary unavailability of the location server to receive a position update (dependant on the location service algorithm employed). Furthermore location inaccuracy can occur as a result of mobility induced errors, as the optimal update interval largely depends on the vehicular speed, road topology and density of vehicles. To clearly distinguish between location service inaccuracy and the negative impact of vehicular characteristics such as mobility, transmission range and vehicular density, a detailed study of geo-routing performance over varied vehicular topological conditions is also performed.

The remainder of the paper is structured as follows: Section 2 discusses related work in this field, with Section 3 outlining the negative impact that stale location information has on geo-routing as well as the occurrence of mobility induced errors. Section 4 discusses the simulation environment and quantitive performance analysis performed. Finally Section 5 concludes the paper and outlines future work.

2 Related Work

A location service has a large impact on the geo-routing protocol as its performance is entirely dependant on the locations service accuracy and scalability. As acknowledged recently in [1, 2], a major hurdle for vehicular ad-hoc networks is the complexity associated with maintaining location services, often suppressing the potential gains.

Given the non trivial nature of maintaining an accurate and available vehicular location service, it is surprising that much of the research published in recent years devoted to vehicular-specific geo-routing protocols does not focus on the location management method used. Geo-routing protocols such as VADD[3], GOSR[4], MDDV[5], ASTAR[6], ACAR[7] and GPCR[8] assume a perfect or idealised location service whilst others such as GPSR [9], RBVT-P[10], GSR[11], GyTAR[12] and SARC[13] utilise MANET-developed location services that have been shown to suffer from robustness and accuracy issues when applied to vehicular networks. However while the drawbacks are known, this is very rarely included as part of the geo-routing protocol performance analysis even though it represents a necessary component for the correct functioning of the routing protocol. In some cases if their performance were to be considered in conjunction with the use of MANET-developed location service, they can often be out performed by traditional routing protocols, negating the purpose of their original inception. To highlight the negative performance effects that a location service can have on a geo routing protocol, it is shown in [14] that the routing overhead for GPSR is significantly higher than topology based routing protocols like AODV and DSR, predominantly because of the overhead incurred as a result of the location service. Furthermore, GSR uses a location service that is dependant on global flooding thus scalability is not guaranteed and GSR only achieves similar results to AODV.

Proactive location services such as the Hierarchical Location Service (HLS) [15] and the Geographical Location Service (GLS) [16] do not consider street layout, contribute significantly to the routing overhead incurred in the network and also the very frequent message exchanges may interfere with data transmissions leading to packet drops. RLS [17], used by GSR, relies on initial global flooding so does not scale well. [18] presents PLS, where instead of using the last known location of a node for the location service reply, the location service tries to extract the mobility pattern of the node and predicts its actual location. The Dead Reckoning-Based Location Service [19] adjusts the periodic dissemination of geographic information based on a first order deterministic mobility prediction model. Mobility Prediction based GLS [20] improves GLS by adapting the periodic location maintenance with two prediction models deterministic first order and history-based first order Markovien.

Thus, many location services have been developed based on generic MANET characteristics but may not perform efficiently in vehicular environments. Subsequently, vehicular-specific location services have been proposed. Gerla et al propose a solution, V-Grid [21], a dual location service with functionality to exploit the intermittent existence of Road-Side Unit (RSU) infrastructure and another location service to operate in strictly ad-hoc vehicular networks. The performance of the purely ad-hoc location service can however quickly deteriorate and requires the use of a dedicated truck to record vehicle registrations in given areas which is not always a feasible approach. Chang et al described the Intersection Location Service (ILS) in [22] where vehicles near intersections represent location servers and a Chord ring is used as a fault recovery mechanism when the corresponding location services go out of service. This approach is again limited by the excessive overhead associated with maintaining mobile location servers and overlay "stretch" between the Chord overlay and the MANET underlay hops. Inconsistency of the Chord overlay, possibly leading to stale or unavailable location servers, was also not investigated. PHLS [23] presents a similar approach to PLS but is hierarchical exhibiting the limitations of traditional MANET client-server location services and does not account for changes in vehicle direction. VLS [24] does not describe the performance overhead implications associated with location server maintenance or provide a fault-tolerance mechanism to ensure location server availability in temporary void areas. MALM [25] and PLM [26], present a localised approach to maintaining location information by exchanging historical location information with its neighbours. Whilst this passive approach yields performance results exhibiting low overhead, it depends on vehicles opportunistically encountering one another or encountering a vehicle that can inform the source about the destination. This can introduce considerable, possibly indefinite, delays as well as rendering this service unusable in terms of success rates i.e. successful packet delivery can't be quantified or guaranteed as it's based on opportunistic vehicle encounters. The authors overcome this by proposing an on demand query mechanism but only query one hop neighbours limiting the scalability of the system.

Therefore the challenge of providing an accurate, available and scalable location service for vehicular networks is a difficult one, as acknowledged in many publications including most recently in [27]. Before a solution can be devised, the impact of the location inaccuracy on a geo-routing protocol should firstly be examined to gain an understanding into what inaccuracy can be endured and to investigate the effects of inaccuracy on the routing protocol. Some attempts have already been made in literature. Helmy et al have published a number of papers in this space [28, 29, 30, 31] but are mainly concerned with the specific failures of the face changing algorithm in GPSR. More recently a study over sensor networks was conducted [32] but only considered a small number of nodes with no mobility and very short transmission ranges. These studies do not consider the inherent characteristics of vehicular networks and as such do not consider the road layout, possible distance or the unique impact of the speeds associated with vehicles.

3 Mobility Induced Errors and Inaccurate Location Service Positions

It is important to distinguish between mobility induced errors and errors caused as a result of location service inaccuracy though they may impact on each other. The possible effects are now described.

Geo-routing protocols typically rely on greedy heuristics in order to route a packet. The next hop is chosen based on the neighbour node is geographically closest to the intended destination. Due to temporary partitions in a network and the non uniform distribution of nodes, packets can reach a point that is still not within radio range of the destination and where greedy routing is no longer possible. This is referred to as the “local maxima” or a “void” in the network. A recovery mechanism is used to circumvent this problem, the specifics of which differ depending on the routing protocol employed. In the case of GPSR, a method known as perimeter mode routing is employed to circumvent void areas based on planarized graphs such as the Relative Neighbourhood Graph (RNG) or the Gabriel Graph (GG). Since no greedy neighbour node is available, a next hop node is chosen based on the Right Hand Rule. However, the edge between sending node and receiving next hop neighbor should not cross the edge between origin node and destination. However node mobility can easily induce routing loops for face routing if the graph is not planar. This can easily cause a routing loop with a packet eventually being dropped when the TTL of 64 has decremented to 0. An example of how this occurs is described in [11]. Packets can also be dropped as a result of the TTL being reached when the intended destination vehicle has left the network before a packet can be delivered or because of exceptionally long perimeter routes. Furthermore vehicular mobility in opposite directions can contribute to excessively long routes as the packet may not always be routed progressively towards the destination as interpreted by the routing protocol.

Furthermore a packet may be discarded as a result of a transmission error if the WLAN retry threshold is exceeded. This may be the result of collisions or because of the intended next hop node moving beyond the radio range of the transmitting node. Whilst an increase in density can improve the packet delivery success rate as it become increasingly less likely that a source or interim node will become isolated, the increased neighbour density for next hop routing may also result in an increase in the number of neighbours on the radio range perimeter that may be chosen as a result of the greedy algorithm. Furthermore vehicular mobility i.e. source and destination vehicles moving in opposite direction may exacerbate this issue. An example of how this can occur is seen in Figure 1a. Vehicle A chooses vehicle B as the next hop vehicle according to the greedy heuristics employed in the geo-routing protocol algorithm and routes to the position stored in its neighbour table, *B(old)*. However B has actually moved beyond the radio range of vehicle A and is now at position *B(new)* but the entry has not been phased out of A’s neighbour table. In this case, A will attempt to transmit and the packet will be eventually be dropped as the WLAN retry threshold will be exceeded. Some routing protocols have suggested link breakage modifications to the 802.11 MAC in order to choose an alternative neighbour, if such a neighbour exists. This scenario could also occur if a destination vehicle has reached its destination thus leaving the network but has not yet been phased out of the source vehicles routing table.

Vehicular mobility can cause frequent temporary partitions in the ad-hoc network causing source or interim next-hop vehicles to become disconnected from their neighbours. Packets can be discarded if a source vehicle has become isolated, temporarily having an empty neighbour table, thus this node can cannot query a destination vehicle's location. This is illustrated in Figure 1b.

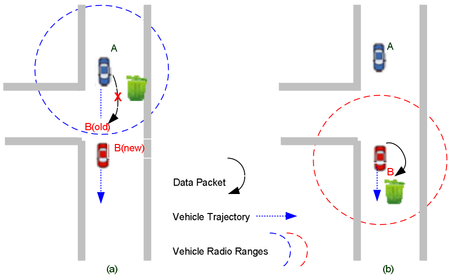


Fig. 1. WLAN Retry Threshold Exceeded and Source Node Isolation

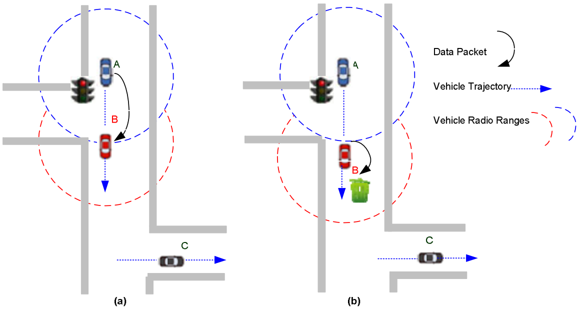


Fig. 2. Mobility Induced Error – Interim Node Isolation

Furthermore an interim vehicle can become isolated such as in Figure 2. In Figure 2(a) vehicle A chooses vehicle B, a vehicle on the periphery of its radio range as the next hop vehicle. Vehicle B successfully receives the packet but subsequently moves outside the radio range and becomes temporarily isolated from the ad-hoc network. This results in a packet drop. While the packet dropped may represent an unsuccessfully delivered data packet, it may also represent a dropped location update packet leading to inaccuracy if the location service were to be subsequently queried. It is suggested in [27] that vanet routing protocols should exhibit four properties, one of which is the implementation of a store and carry paradigm for delay tolerant applications to cope with temporary network disconnections. Such a strategy could minimise the problems outlined in Figure 2 but would have limited usefulness regarding a location update packet as the time passed may directly related to the accuracy of the position.

As stated, location service inaccuracy can lead to inefficient and incorrect routing decisions. If the target destination position received by the geo-routing protocol is inaccurate, the algorithm cannot function correctly. Therefore greedy neighbour nodes are chosen incorrectly and perimeter mode decisions are made with the incorrect location in mind. An illustration of how a packet can be routed incorrectly can be seen in Figure 3. Vehicle A wishes to route to vehicle B. The location service returns vehicle B's last registered position in the location search index, *B(old)*. This situation could occur because the location update interval is too large or more likely because vehicle B's location update message failed to reached a location server and hence its location was not updated. Vehicle A routes in the direction of the stale position with the packet eventually dropped when the TTL is reached or because of failure of perimeter routing to find the destination i.e. no edge to route.

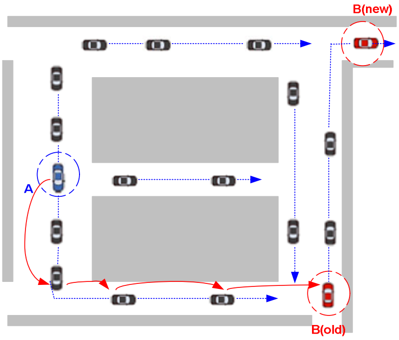


Fig. 3. Geo-routing with Stale Location Service Information

Therefore a number of factors contribute to routing failure and packet drops and are categorized as follows in next section:

Source Node Isolated: Packets are discarded as a result of a vehicle having no neighbour table entries. This can be caused by a temporarily partitioned network, especially in a sparsely connected network.

No Edge to Route: A packet has traversed the perimeter and has arrived back at the node at which it entered perimeter mode without finding the destination. This can occur because no route exists, because the destination vehicle may have left the network or because of inaccurately reported location information.

WLAN Retry Threshold Exceeded: Packets are dropped by the WLAN MAC because of consistently failing retransmissions, exacerbated by routing loops and stale neighbour tables.

TTL Reached: This represents the packets dropped due to the expiration of a packet's Time-To-Live (TTL) field (64 hops) without ever reaching the intended destination.

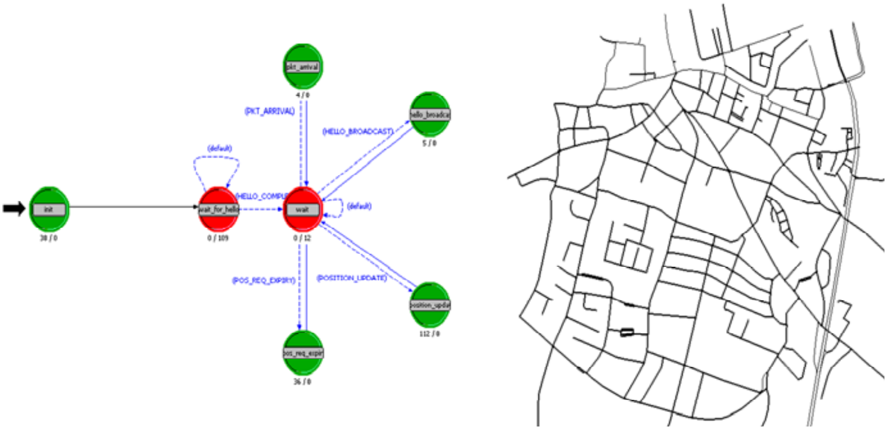
Interim Node Isolated: A node receives a packet just as it becomes isolated in the network.

4 Performance Evaluation

4.1 Simulation Models and Scenario Establishment

While many VANET-specific routing protocols have recently been proposed, no clear “one size fits all” solution routing protocol for unicast vehicular communications has yet emerged as a prevalent standard. Greedy Perimeter Stateless Routing (GPSR) acts as the base geo-routing protocol for this simulation study. We acknowledge that GPSR has recognised drawbacks in vehicular networks which can affect the packet delivery success rate however this is immaterial to the content of this study as we are not concerned with the specifics of the geo-routing protocol but rather the negative effects that mobility and location inaccuracy has on base-line routing protocol performance. VANET specific geo-routing protocols that significantly improve on GPSR routing performance were listed in Section 2. Despite the individual merits that a particular routing protocol exhibits over another, they all require a location service to accurately report the location of the destination node. If the destination reported is inaccurate this will ultimately lead to their respective routing algorithms making incorrect routing decisions.

A GPSR model has been developed in OPNET, as seen in Figure 4a. This is the first publicly available stateless geo-routing model that the authors are aware of that is available in OPNET. A previous model was referenced in [33] but the model is not freely available. Our model has been implemented according to the specification in [9] using the RNG for planarization.



(a) (b)

Fig. 4. (a) OPNET GPSR Model **(b)** SUMO Extraction of $1500m^2$ Area of Cork City

Vehicular movement is modeled in OPNET via a custom mobility model based on trace files generated by SUMO [34], a microscopic road traffic simulation package. The vehicular spatial environment is based on an urban road topology of Cork City in Ireland, by importing detailed road layouts from OpenStreetMap.org and inserting random traffic flows. SUMO simulates vehicle behaviour according to the Krauss vehicle following model. This model regulates vehicle speed and behaviour based on the movements of the preceding vehicles. Figure 4b illustrates the SUMO road topology generated for a 1500m^2 area.

We have limited the maximum speed of the vehicles to 50 km/h, the speed limit restriction within Cork City, as the default speed restrictions associated with the road types imported by the OSM map were too high for safe motoring within an urban environment. The speed profiles for two random vehicles are shown in Figure 5a. It can be seen that since that in the congested network, the vehicle movement is constrained by traffic congestion where as the other vehicle speed profile is relatively free flowing. We also consider a broad spectrum of traffic densities with SUMO injecting cars into the network at a specified Vehicle Arrival Rate (VAR). A low density network is represented with 2 vehicles per second injected into the network (VAR=2). A busy but somewhat free flowing density is considered with VAR=3 v/s and a densely populated scenario with a VAR=4.5 v/s is also considered. These arrival rates are dependant on the area size and were chosen by examining the GUISIM output while ensuring no collisions occurred for the dense scenario. The number of vehicles in the metropolitan area over the duration of the simulation is depicted in Figure 5b. Vehicular presence times are shown in Figure 5c for a VAR of 2 v/s. Vehicles exist in the simulation for approximately 170 seconds on average.

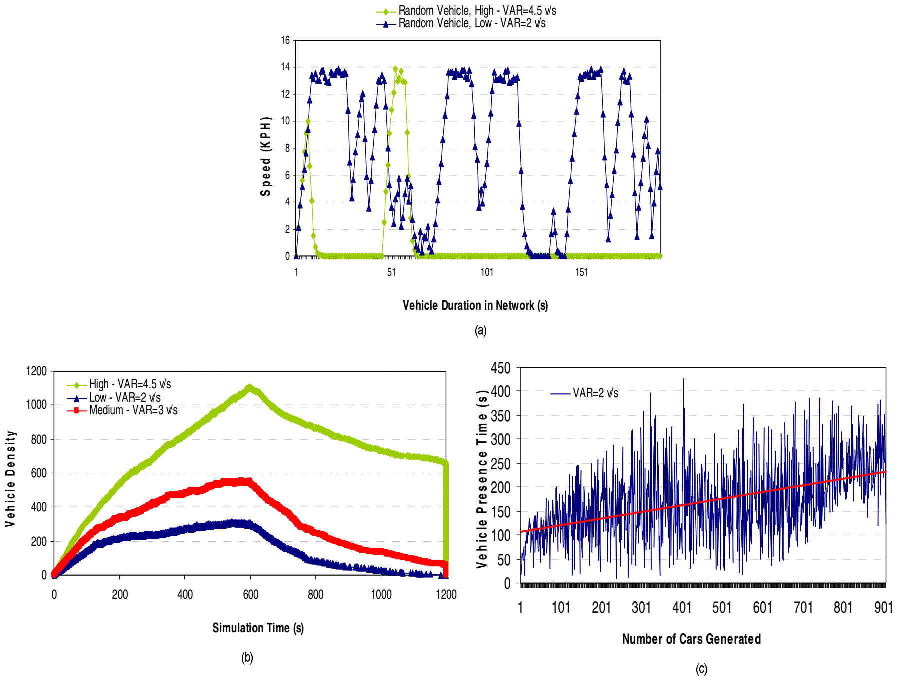


Fig. 5. **(a)** Random Vehicle Speed Profiles **(b)** Vehicular Density **(c)** Vehicle Presence Times

Within OPNET, a square grid of 1500m^2 is employed. All vehicles use the IEEE 802.11 MAC with a 2.4GHz radio interface and a transmission speed of 11Mbps. Radio propagation for these urban simulations follows the Two Ray Ground model incorporating the effects of path-loss with an exponent of 4dB, a log-normal shadowing component and antenna heights of 1.5m when determining the transmission range. Each simulation represents a time period of 1200 seconds. Vehicles are injected into the network for 600 seconds with the remaining time providing an opportunity for vehicles to complete their journeys. A vehicle generates a location query message approximately 10 seconds (varies slightly with jitter) after it enters the network, with subsequent requests made at 100s intervals. Every vehicle represents both a vehicle that will periodically query for a location and a target destination vehicle. Two custom OPNET models are used to generate these data queries as well as to provide the location service to the geo-routing protocol respectively.

4.2 Experimental Results

It is our objective to obtain insight into the negative impact of mobility and location service inaccuracy on a geo-routing protocol. Given this, we must carefully design the simulation to distinguish between mobility induced and network based parameters that can impact on the successful delivery of a packet vs packets drops that occur as a direct result of inaccurate reported locations. Thus we first examine the impact of several key influences such as vehicular density, transmission range as well as the distance between source and destination vehicles i.e. range of data queries, on the geo-routing protocol performance. For this reason we assume the availability of the location service at no additional overhead. Unless specified otherwise, source and destination vehicle pairs are randomly chosen. It is assumed every vehicle knows its own position. A summary of the parameters used can be seen in Table 1.

Table 1. Simulation Parameters

Wireless Standard	802.11b
Propagation Model	Two-Ray Ground + Log-Normal Shadowing
Antenna Heights	1.5 m
Radio Range	50m-200m
Area Size	1500 m^2
Vehicle Injection Rate	Low: 2 v/s, Medium: 3 v/s High: 4.5 v/s
Vehicle Speed	0-50 km/h
Beaconing Interval	uniform (500, 600) ms
Nbr Expiry Interval	constant (1) s

4.2.1 Vehicle Transmission Range

We next evaluate the impact of a varied transmission range on the Query Success Rate (QSR), with a query defined as any source to destination communication. Data messages are generated for random target vehicles within the urban topology. Experimental analysis on vehicular geo-routing protocols [7] and location services [24, 35, 36] often opt for overly optimistic radio ranges such as 250m. In contrast, the simulations we describe assume a transmission range of 100m and in this section we evaluate the effects of a radio range as low as 50m. It can be seen in Figure 6a, that significant deterioration in the QSR can be noted as the vehicle radio range is reduced. A decrease from 62% to 6% is observed as the transmission range is reduced from 200m to 50m for the scenario with a VAR = 2 v/s. Similar decreases in QSR can be noted for the medium and highly dense scenarios. A short radio range will result in smaller neighbour tables thus limiting the number of potential next hop neighbours available to the vehicle for greedy routing. This can lead to excessively longer packet routes as perimeter routing will be more frequently employed. It also reduces the likelihood that the position of the destination can be resolved directly from the source vehicle's neighbour table, increasing reliance on the location service as shown in Table 2 where 13.1% of queries are directly resolved for a 200m transmission range in comparison to 3.1% for a 50m transmission range. Similar results were noted for the medium and highly dense scenarios. Furthermore, the possibility of a partitioned network increases as the radio range is reduced along with the high probability that an end to end route does not exist between the source and destination. This can be observed in Figure 6b. As the transmission is reduced it can be observed that the number of packets dropped as there's no edge to route on increases. This is as a result of perimeter mode routing being invoked more frequently and the completion of the perimeter failing to locate the destination or another node that can route greedily to the destination. Furthermore the number of packets dropped as a result of source nodes becoming isolated increases. The numbers of packets discarded due to the TTL being reached maintains steady values for all transmission ranges evaluated.

It could be anticipated that the number of hops taken to resolve a query would increase as the radio range is reduced but we observed that the average number of hops and latency remained in the range of 2-4 hops. This is because this is representative of those packets successfully received, with transmitted packets being dropped for higher hop counts. This can be attributed to the higher risk of partitioning and isolated nodes. Comparable values were noted for the medium and highly dense scenarios.

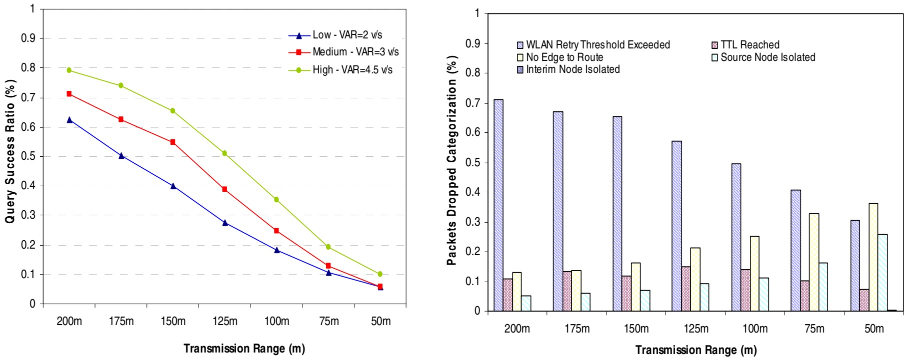


Fig. 6. **(a)** Query Success Rate vs Transmission Range **(b)** Packet Drop Categorization vs Transmission Range VAR = 2 v/s

Table 2. Neighbour Resolved Locations, Hop Count, Query Latency vs Transmission Range

Radio Range	200m	175m	150m	125m	100m	75m	50m
Locations Resolved Via Neighbour Table (Packets Transmitted)							
VAR 2 v/s	13.1%	10.7%	8.7%	7.3%	5.6%	4.5%	3.1%
Average No of Hops to Resolve Query (Packets Received)							
VAR 2 v/s	3.1668	4.278	4.315	3.924	3.575	2.828	2.173
Average ETE Query Latency (ms) (Packets Received)							
VAR 2 v/s	3.339	3.721	3.684	3.284	2.98	2.104	1.48

4.2.2 Query Range

We next examine the impact of query range, the distance between a source and destination vehicle and its impact on the success rate of a packet. Given an area size of 1500m^2, the maximum distance that is possible between source and destination vehicles is 2121m when they are located in diagonally opposing corners of the area border. Up until this point, target destinations have been generated randomly, anywhere within the boundary of the network topology.

In Figure 7 it can be seen that an increase in the distance between the querying vehicle and the target destination has a dramatic effect on the QSR, most notably when the query range extends from 0-100, i.e. direct neighbours of the source, to 100-200 i.e. reliant on geo-routing. A steady decrease in QSR is noted as the distance increases though it can be observed that density improves the QSR slightly as more routes are available to forward the packet. The decrease in QSR can be attributed to the increasing likelihood of the network becoming partitioned as the distance increases, that the TTL may be reached or that a neighbour may have moved out of range of an interim hop. No packets were successfully received in the low density network past the range of 700-800m. While packets were received in the medium and higher density networks, a steady decline in the QSR is noted. It can also be observed in Table 3 that as expected there is an increase in the end-to-end delay for received packets as the number of hops increases, with 1 hop approximately corresponding to 1ms in delay for all vehicular densities. These results highlight the inadequacies of multi-hop routing over very large distances and the possible benefits if some infrastructure were available to support V2V packet routing. An outline architecture proposing use of Road-Side Units to aid V2V communications has previously been proposed by Gerla et al [21].

4.2.3 Location Service Inaccuracy – Time-Related and Absolute Position Errors

Now that we have studied the vehicular environment under the influence of a number of topological and mobility based parameters, we next examine the impact of time related position errors on the location service accuracy. Some location service protocols rely on static location update intervals to update the vehicle mappings within the location service index. This location update interval directly affects the accuracy of the position information available. It can be expected that a static update interval of *t* could lead to the return of inaccurate information if information is queried at time *t-1*, *t-2* and so on. The location information stored for a vehicle could, by this time, be stale. While this might not cause a major drop in geo routing success given a sufficiently low update interval the most likely reason for the return of inaccurate location information by the location service resulting in packet drop is as a result of a periodic update messages being delayed or dropped either as a result of a collision or lack of existence of a route to location service index. Thus the last registered position is returned by the location server. If update packets were to be frequently dropped, highly inaccurate location information could be returned. Deterioration in the packet delivery rate of GPSR can be seen when there is an increase in the time-related position error as shown in Figure 8a. The baseline QSR performance is already poor with 18.1%, 24.6% and 35% observed for the low, medium and highly dense scenarios respectively when no error is introduced.

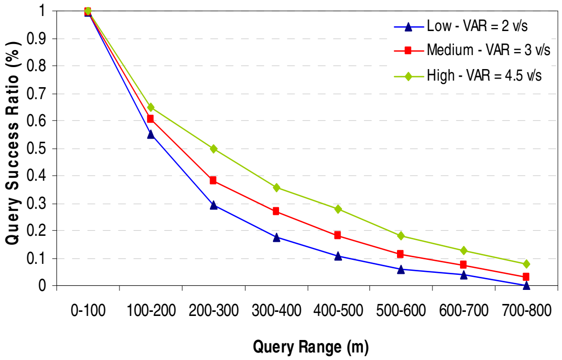
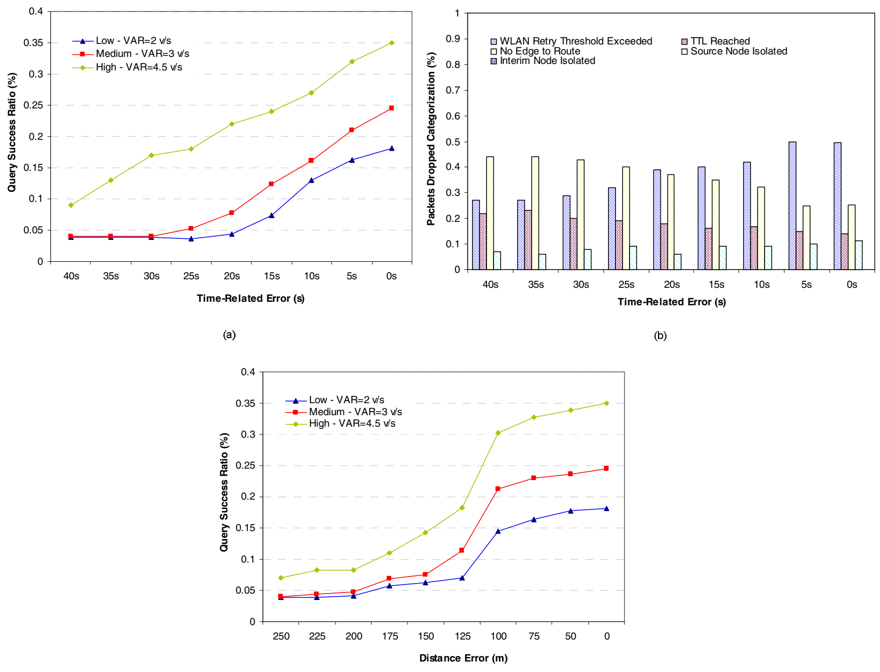


Fig. 7. Query Success Rate vs Query Range

Table 3. Hop Count & Query Latency vs Query Range

Query Range	700-800	600-700	500-600	400-500	300-400	200-300	100-200	0 - 100
Average No of Hops to Resolve a Query (Packets Received)								
VAR 2 v/s	-	9	8.08	8	5.4	4.43	2.4	1.02
VAR 3 v/s	13.3	11.3	9.43	7.35	5.52	4.02	2.44	1.01
VAR 4.5 v/s	14.9	11.6	9.73	7.9	5.5	4.13	2.71	1
Average ETE Query Latency (ms) (Packets Received)								
VAR 2 v/s	-	8.9	7.33	7.3	4.68	3.79	1.16	0.3
VAR 3 v/s	14.5	12.2	9.45	7.1	5	3.5	1.82	0.3
VAR 4.5 v/s	15.1	11.9	9.62	7.56	5.8	3.67	2.1	0.3

It can be seen that the QSR decreases from 18.1% to 3.9% as the error increases from 0-40s for a VAR of 2 v/s. A very small amount of packets are still received up to the 25s error even though a vehicle could have theoretically travelled a distance of 325m from the report position. This is as a result of small periods of congestion in certain areas of the network such as intersections where the network is not free flowing. Furthermore, the QSR never decreases to 0% because the introduced error is only applicable to those destination queries resolved via the location service and not directly via the neighbour table. The inaccurate location information results in the incorrect operation of the routing protocol with the packet forwarded towards an old location. Thus packets will be routed "greedily" to incorrect neighbours and will traverse incorrect faces when in perimeter mode. While there is a slim possibility that an interim node encountered on the path has a record of the destination in its neighbour table and that the packet may be successfully delivered – the more likely result is that the packet will continue to loop until the TTL has fully decremented or until a full perimeter is traversed and no viable next edge is found as shown in Figure 8b. The geo-routing cannot make correct routing decisions with inaccurate location information. We found that the QSR for the highly congested topology is impacted less negatively. This is a result of the high VAR of 4.5 v/s. The network becomes densely populated and this heavy congestion results in little or no vehicle movement i.e. vehicles are stuck in heavy traffic. As a result their reported position remains relevant for a longer time period, regardless of the level of time error being purposefully introduced. In contrast for a VAR of 3 v/s, considered to be a busy yet moving traffic flow, it can be seen that introduced time error has an impact all the way through the simulation.



(a) (b)

(c)

Fig. 8. (a) Query Success Rate vs Time-Related Distance Error **(b)** Packet Drop Categorization vs Time-Related Distance Error **(c)** Query Success Rate vs Location Service Distance Error

Recent location service algorithms typically require a vehicle to update its location after a pre-defined distance has been travelled in order to overcome the drawbacks of static time based update intervals. This distance is usually 100m but this typically assumes a transmission range of 250m. We introduced a distance error by referencing a vehicle's past positions from its trajectory list, determining the distance travelled in each increment until a position is returned that is equal to or slightly greater than the specified distance error required. As previously noted the baseline QSR is already poor with no location error. It can be seen in Figure 8c, that once the transmission range of a node is exceeded the QSR deteriorates quickly with a few occasional queries resolved from long perimeter routes with entries for the destination in their neighbour tables. Furthermore even though a vehicle has travelled a distance, they may not be necessarily be out of range of their old reported position depending on the road layout i.e. they could have travelled around a U-shaped or curved bend in the road and have only travelled a short Euclidean distance from their old reported position, thus can still be found via the unit disk graph transmission assumption. It can be seen however that like the time related errors, QSR quickly decreases such that only direct neighbour queries can be solved from neighbour table entries. It can be seen that for the highly dense scenario the QSR did not drop such that all location service queries failed but this is because the vehicles may not have travelled the distance required to introduce a sufficiently large error and hence we are the error introduced is limited. The QSR shown for the medium and low density scenarios is more indicative of the effect of the error.

5 Conclusions and Future Work

This paper describes the impact on a geo routing protocol of vehicular mobility characteristics such as transmission range, query range, vehicular density as well as quantifying the impact of explicit location errors. Paper findings provide guidelines for what query success rate can be expected, given particular vehicle mobility scenarios and absolute location inaccuracy. Future work will consider the availability and fault tolerance of the location service, a particularly challenging topic in multi-hop vehicular networks with high vehicle speeds. Location server availability for update will have a direct impact on accuracy and availability for query is vital if communication is even to be possible. We will also examine the possibility of exploiting vehicular characteristics such as the intermittent existence of roadside unit infrastructure to improve connectivity and aid location service scalability.

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